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A Comparative Analysis of Policy Instruments Promoting Green Electricity under Uncertainty

1. Introduction

The European Union wants to increase its use of "renewable energy". The main driving forces behind this ambition seem to be considerations about energy security and a strategy to complying with the Kyoto Protocol cost-effectively. The EU Parliament has issued two directives on this matter. One saying that in 2010 shall 12% of EU's electricity production be based on renewable energy resources (EU, 2001). The other sets up the target that in 2010 shall at least 5.75% of EU's use of transportation fuels be renewable energy (EU, 2003). Both directives urge the member states to take on national, indicative targets for the use of renewable energy in electricity production and transportation, respectively. The member states are, however, free to choose the instruments by which they attain their national targets. And, at least when it comes to promoting production of so-called green electricity, a variety of instruments have been employed. For instance, Germany and Denmark have systems with so-called feed-in tariffs while the authorities in the UK have used competitive bidding systems to procure a given amount of green electricity. In 2003, Sweden launched a system with green electricity certificates under quota obligation. At the same time, the EU appears to have the ambition to integrate the member states' markets for green electricity and to employ a single policy instrument for the whole union. Given this and a future likely to contain more ambitious targets for the production of green electricity, it seems relevant to analyze the *pros* and *cons* of available policy instruments.

Several studies have been conducted on this topic. For instance, Gan *et al.* (2005) study the major systems used in Europe. Gan *et al.* and others argue that feed-in tariffs provides with more flexibility than do systems with green certificates or competitive bidding systems, which is of importance in an uncertain world. It has for long been known that uncertainty may influence the optimal choice of policy instruments and/or optimal control levels. However, so far the literature on how to promote production of green electricity appears to have dealt with the effects of uncertainty in an *ad hoc* manner. References are often made to the classical work of Weitzman (1974), see *e.g.*, Menanteau *et al.* (2003). However, it is not evident that Weitzman's work is directly applicable on the case of promoting green electricity.

The paper presented here studies, in a more systematic way than previous literature, the implications uncertainty regarding *i.a.* future production costs of green as well as conventional electricity has on the optimal choice of instrument to promote production of green electricity. The objective is to identify relevant effects the regulator need to assess before being able to make an informed choice. The instruments studied are

(i) a feed-in tariff, *i.e.*, an obligation for retailers of electricity to buy whatever quantity of green electricity that is supplied at a price determined by the regulator,
(ii) a so-called environmental bonus, *i.e.*, a fixed premium to producers of green electricity over and above the market price on electricity,
(iii) an obligation for the retailers to procure a certain quantity of green electricity, and
(iv) green electricity certificates, *i.e.*, an obligation for retailers to purchase green electricity in an amount equal to a given share of their total electricity sale.[1]

The rest of the paper is organized as follows. Section 2 describes the instrument subject to analysis and lays out the ground for a controlled comparison of the instruments. Section 3 investigates the effects of *i.a.* uncertain production costs. Concluding remarks are given in Section 4.

2. Instruments Promoting Green Electricity

This Section describes the functioning and the effects of the four policy instruments mentioned above. It is here assumed that the regulator is fully informed about future production costs as well as future demand for electricity. Throughout the analysis we assume competitive as well as law abiding behavior by producers, retailers and consumers of electricity. Transaction costs and income effects are assumed to be insignificant.

[1] The analysis on green certificates presented here builds on Carlén *et al.* (2005). It adds to that study by a more thoroughly discussion about the effects of so-called safety valves in green certificate systems.

Under a system with green certificates retailers of electricity are obliged to acquire and hold a certain number of certificates for each unit of electricity they buy and sell, the so-called quota obligation.[2] At the same time, producers of green electricity obtain a green certificate for every unit of green electricity they produce. Hereby, a demand for and a supply of green certificates are established. Given that retailers comply with the system[3], the regulator control the production of green electricity by deciding how many certificates the retailers must purchase and hold per electricity unit sold.

Figure 1 illustrates a system with green electricity certificates. Let D denote the demand function for electricity during a compliance period (usually one year long) commencing some, say five, years from now. We assume that the demand for electricity is completely inelastic, *i.e.* irrespectively of the price the amount of electricity demanded and consumed is the same – here Q units. This is clearly unrealistic but simplifies the analysis considerably since we then avoid the rebound effect green certificates have on the demanded quantity of electricity. Let Q_G denote the quota obligation during the compliance period in focus here. As mentioned above, this quota amounts to a predetermined fraction of the electricity consumption, *i.e.*, $Q_G=\alpha Q$, where $0 < \alpha < 1$. The policy parameter α may be constant over compliance periods, but need not to be. As Figure 1 is drawn the green certificate system will induce additional production of green electricity. In fact, had there been no certificate system only conventional electricity would have been produced. This is evident since the entire marginal cost function for green electricity (MC_G) lies above the electricity price that would have emerged in the absence of the green certificate system, namely P_0. Given this and no possibilities to transfer certificates between compliance periods, both the demand for certificates and the production of green electricity will equal the quota level Q_G.

Since this system of green certificates mills in Q_G units of green electricity, the supply curve of conventional electricity (MC_{conv}) must shift to the right with Q_G units. So, under the certificate system the relevant supply curve for conventional electricity is MC^2_{conv}. The competitive electricity price then equals P_1. Given competition amongst producers of green electricity they must, for producing Q_G units, receive a total per unit revenue of P_G. Since they get P_1 from the electricity market, they must receive a certificate price equal to t_1 ($=P_G$-P_1). In

[2] In the Swedish system, the obligation is levied upon the consumers of electricity but handled by retailers on the behalf of the consumers.

[3] This can only be expected if he cost of non-compliance exceeds the cost of being in compliance – which at the margin equal the certificate price. For that purpose, we assume a prohibitive penalty for non-compliance behaviour.

total the producers of green electricity receive revenues from certificate sales corresponding to the grey area in the Figure ($=t_1Q_G$). It is here assumed that retailers finance their expenditures on certificates by an extra fee levied on consumption of electricity. The consumer price thus equals $P_1+t_1Q_G/Q$.[4] The cost of satisfying the electricity demand of Q units under this system of electricity certificates corresponds to the area under MC_G within the interval 0-Q_G *plus* the area under MC^2_{conv} within the interval Q_G-Q. The green producers' producer surplus corresponds to the area over MC_G but under P_G.

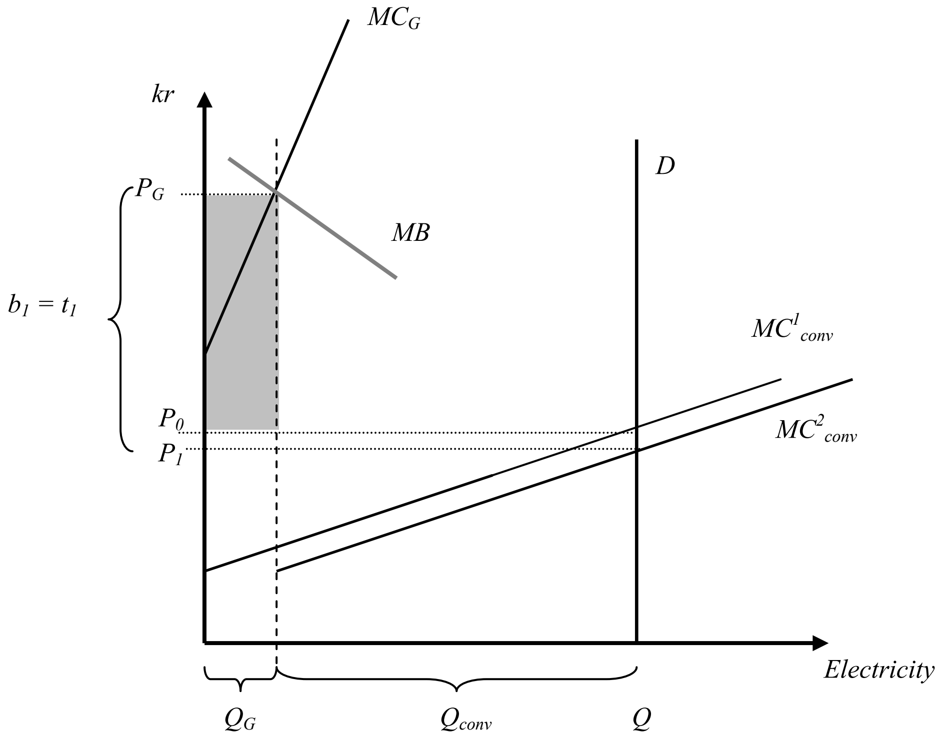

Figure 1 Green electricity certificates

Consider now a policy obligating retailers of electricity to procure Q_G units of green electricity and assume that they for this purpose have constructed a competitive, non-discriminatory auction under which producers of green electricity submit sale offers. In equilibrium, Q_G units will be procured at the unit price P_G. If financed by a fee on electricity consumption this system will be equivalent to the green certificate system above.

[4] Since $P_1 < P_0$, it is possible, although not likely, that certificate systems imply lower consumer prices on electricity. This would happen if the quota obligation is not too large and MC_{conv} are steep around Q while the marginal costs of green electricity are low and increase only slowly in produced quantity.

Consider now a fixed feed-in tariff equal to P_G. At this price producers of green electricity are willing to supply Q_G units of green electricity. Also under this instrument the most costly units of conventional power are the ones being substituted for green electricity. So, this system will have the same impact on the producer price on electricity as the certificate system. And, if financed by an extra fee levied on electricity consumption, this instrument will induce the same outcome as the two quantity-based instruments described above.

Finally, consider a per unit subvention of production of green electricity. Swedish wind power producers are currently receiving such an "environmental bonus" over and above the electricity price and the certificate revenue. For such a bonus to, by itself, inducing Q_G units of green electricity it must amount to $b_1 = P_G - P_1$. Total revenue per unit green electricity sold then equals P_G. If financed in the same manner as the preceding instruments, it will be equivalent to the other instruments.

To sum up, given full knowledge about future costs and demand schedules, any given production target for green electricity can be attained in several ways at the same costs. The systems studied here are all cost-effective in the sense that they induce the least costly units of green electricity to be produced. It should be noted, however, that we here have ignored any indirect costs of promoting green electricity. For example, the circumstance that these policies, if inducing a substantially higher consumer price on electricity and thereby increasing the price level in the economy, would imply a lower real net-wage, which in turn would provoke households to lower their supply of labor. Hence, to keep its revenues constant the government would have to increase the income tax and thereby further distort the labor market, or have to do the same with some other tax. This type of interaction effects might be substantial (see *e.g.* Parry *et al.*, 1999). Since the four instruments studied here have the same incremental effect on the consumer price on electricity and are financed in the same way, their indirect effects will also be the same. Consequently, the societal costs of these policy instruments will be the same. However, an extra fee on electricity consumption may not be the best way to finance policies promoting green electricity, so it is not clear that the instruments as we have designed them here are the least costly ones for the society. In the subsequent we ignore these types of general equilibrium effects.

If the target level for production of green electricity is set such that, at that level, the cost of an additional unit equals the benefit of such a unit, the policies defined above would not only be cost-effective but also efficient. This is illustrated in Figure 1, where we have drawn a marginal benefit schedule for green electricity (*MB*) intersecting the MC_G function at the target level Q_G. It should be noted that this benefit function does not origin from the environmental cost of additional carbon emissions. This is so because the carbon emissions from energy intensive activities within the EU are capped at the aggregate level by EU's trading system for emission permits for carbon dioxide (EU ETS). Given EU ETS, any additional emission reducing policies targeting electricity production will only result in that the targeted electricity producers increase their net sales of carbon permits, whereby the emissions elsewhere in the trading system increase by that amount. The rationale for promoting green electricity lies instead in that it might

(i) reduce the member states' costs of complying with EU's Burden-sharing Agreement under the Kyoto Protocol (EU, 1998) or the Kyoto Protocol. This is the case if the marginal abatement cost within the EU ETS is lower than the costs of additional abatements in sectors not covered by EU ETS (*i.e.*, non-energy intensive industries, household, the service sector and the transportation sector);

(ii) increase energy security;

(iii) have positive dynamic effects, *i.e.*, reducing the costs of participating in future climate change agreements or facilitating more ambitious such agreements.

We don't have much information to about (ii) and (iii). However, (i) is likely to be the dominating rationale. If so, we know more about the shape of the *MB* function. For Sweden, which, in contrast to most other EU states, has a *national* target for its greenhouse gas emissions, the *MB* function more or less reflects the costs of additional abatements in the Swedish non-trading sector. The reason is that additional abatements of carbon emissions in Swedish electricity production, under the national emissions target, will admit the non-trading sector to emit more and thus avoid abatement costs there. At least for Sweden this implies a *MB* function that is located at a high level and falls rapidly in the amount of green electricity. However, if Sweden would, as suggested by, *e.g.* the Swedish Energy Administration, take on the objective of just complying with EU's Burden-sharing agreement, additional abatements in Swedish electricity production would only imply less net-import of EU ETS permits to Sweden. The *MB* function would then be a rather flat function located at the level of the price on emission permits in EU ETS. For more on these matters, see Carlén *et al.* (2005).

3. The Effects of Uncertainty

In this Section we relax the rather restrictive assumption that the regulator knows future costs of and demand for electricity. The departure for the analysis is a situation where these variables are not fully known by the government, at least not at the point in time when it determines the control levels for the compliance period commencing five years ahead. The uncertainty is assumed to be resolved prior to this period, at least for producers and consumers of electricity, which then act under conditions that in a meaningful way can be modelled as a case of complete and perfect information. Given this, the government will in general not be able to set the control level for any of the instruments discussed above such that marginal costs of green electricity equate marginal benefits of the same. Hence, there will remain distortions at the "market for green electricity" also after the policy intervention. We assume that the objective of the government is to minimize expected efficiency losses.

The assumption of linear marginal cost and marginal valuation schedules is somewhat restrictive, but is made to avoid a need for numerical analyses. The analytical approach is to first investigate the effects of uncertainty regarding (a) marginal costs of green electricity, (b) marginal costs of conventional electricity and (c) future consumption of electricity, respectively, and then to discuss the implications of these uncertainties arising simultaneously. We also discuss efficiency enhancing adjustments of the instruments.

Uncertain marginal costs of green electricity

Figure 2 – corresponding to the upper left part of Figure 1 – depicts a situation where only future marginal costs of green electricity are uncertain and where this uncertainty refers to the location of the MC_G–schedule, not its functional form. The marginal cost function can either lie over, at or below MC_G.[5] The three states of the world are assumed to be equally likely. Hence, MC_G is the expected marginal cost schedule. Since, the efficient production of green electricity is determined by the intersection of the realised MC schedule and the MB function, also the efficient production level will be uncertain. When marginal costs turn out to be higher/equal to/lower than expected, the efficient level is e^*_H / e^* / e^*_L, respectively.

[5] We abstract here from the circumstance that also the benefits of green electricity might be uncertain. However, given the assumption of linear *MC* and *MB* functions this assumption does not affect the optimal control levels or the optimal choice of policy instrument (Weitzman, 1974).

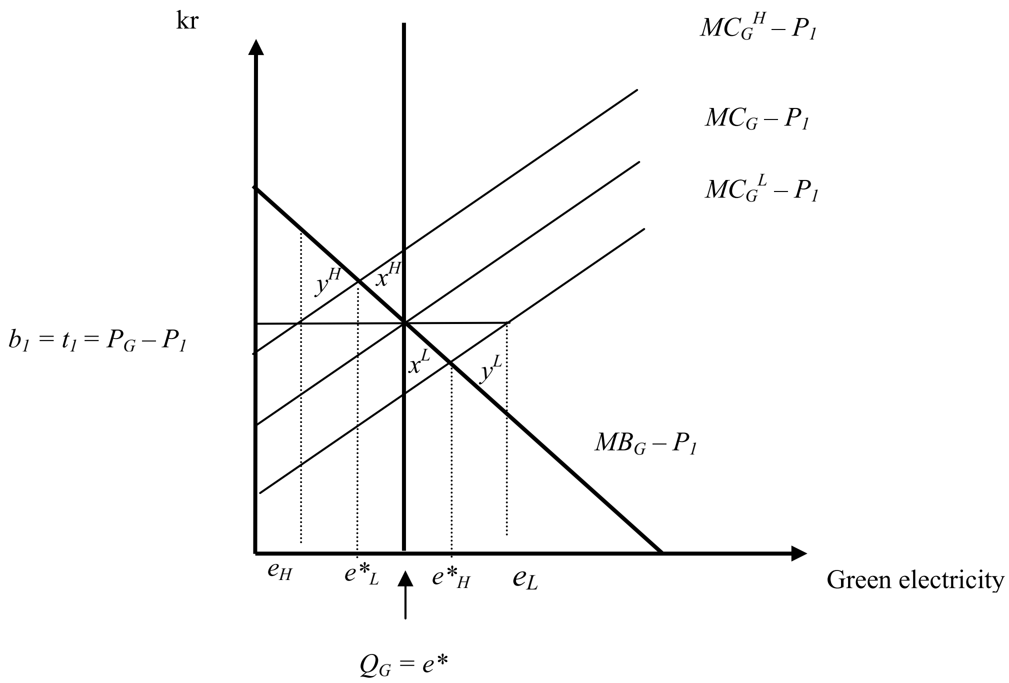

Figure 2 Uncertain marginal cost of green electricity

Consider now a green certificate system requiring Q_G units of green electricity to be produced. Since this requirement is the same irrespectively of which state of the world that materializes, too much (little) green electricity will be produced whenever marginal costs turn out to be higher (lower) than expected. That is, at the margin green electricity is produced at a costs exceeding (falling below) the societal benefits of additional units of green electricity. Only when costs are as expected will the certificate system be efficient. The losses amount to x^H, 0 and x^L, respectively. Hence, the expected efficiency loss of a green certificate system inducing Q_G units amounts to $X = \frac{1}{3}x^H + \frac{1}{3}0 + \frac{1}{3}x^L$. The same goes for a bidding system procuring Q_G units.

Consider now instead a feed-in tariff amounting to P_G or an environmental bonus equal to b_1 (which in combination with the electricity price P_1 gives a per unit revenue equal to P_G). In contrast to the quantity-based policies, the production level under these "price policies" will vary with the state of the world. When costs turn out to be higher than/equal to/lower than expected, the production of green electricity will amount to $e_H/Q_G/e_L$, respectively. Hence, these "price policies" yield too little (much) green electricity whenever production costs turn out to be higher (lower) than expected. Only when costs are as expected will they induce the efficient level. The efficiency losses are y^H, 0 and y^L, respectively. Hence, the expected efficiency loss of the feed-in tariff P_G or the environmental bonus b_I equal $Y = \frac{1}{3}y^H + \frac{1}{3}0 + \frac{1}{3}y^L$.

It can be shown that the control levels studied here are the optimal ones, *i.e.*, for each instrument the chosen control level minimizes the expected efficiency loss. However, the expected efficiency loss will in general vary amongst the instruments. As shown by Weitzman (1974), the relative performance of these policies depends crucially on the relative slope of the MC_G function, and whenever the MC_G function is steeper than the MB function the optimal price policy is associated with lower expected efficiency losses than is the optimal quantity based policy. When the two functions are equally steep expected efficiency losses of the two policies will be equal.

As indicated above, the location as well as the steepness of the MB function for green electricity depends to a large extent on how the country formulates the target for its national climate change policy. Hence, not only will the national climate change policy influence the optimal target level for production of green electricity but it might also affect the optimal choice of instrument to promote production of green electricity.

We have her shown that when the costs of green electricity are uncertain all instruments studied here are associated with efficiency losses. However, more sophisticated instruments are available. For instance, Roberts and Spence (1978) tells us that, in the case studied here, a green certificate system with the quota Q_G in combination with an assurance by the regulator to issue additional certificates if the price reach a certain predetermined level and to purchase certificates if the price falls to a certain level would – if well designed – be more efficient than the certificate system designed above. In the simple setting assumed here such a policy would be capable of inducing the efficient production level in all states of the world. However, in general also this type of systems will be associated with efficiency losses, albeit smaller ones than those associated with the other instruments. Full fledged such systems are seldom observed in the real world, though.

A simplified version of the instrument outlined by Roberts and Spence (1976) has been proposed and debated in the context of climate change policy, namely the so-called safety valve approach (see *eg*. Pizer, 2002). In a certificate system with a safety valve the retailers are still obliged to hold certificates in the amount of Q_G. However, they have now the opportunity to buy certificates from the regulator at a predetermined price – the safety valve level. Certificates issued by the regulator in this way are, however, not associated with production of green electricity. In our simple setting it is easy to see how such a safety valve can be efficiency enhancing. For instance, assume a safety valve equal to the level at which the MC_G^H schedule and the MB function intersect in Figure 2. Then, when MC_G^H function is realized, producers of green electricity would only be able to sell e^{*H} units of green electricity profitably. For additional units the producers would require a price exceeding the safety valve level, whereby they would find no buyers for these units. The retailers would buy Q_G-e^{*H} certificates from the regulator. Since the production of green electricity in the high state of the world would equal e^{*H}, the efficiency losses under this certificate system would be 0, 0 and y_L, respectively.

It should be noted that a penalty fee effectively works as a safety valve. However, in general the optimal safety valve lies below the penalty fee that induces compliance behavior in most states of the world (see *e.g.* Mandell 2004). And, in the presence of market power, the optimal safety valve is even lower (Carlén, 2002). There seems to be a political resistance to use safety valves. This is not easy to understand since if the proponents of green electricity are correct in their expectations of low future costs of green electricity a reasonably set safety valve would not often be binding and the inclusion of such a safety valve might enable skeptics of green policies to agree upon more ambitious target levels. In fact, the optimal safety valve policy contains a quota obligation exceeding Q_G.[6]

It should also be noted that allowing retailers of electricity to bank and/or borrow certificates will mimic the system discussed in Roberts and Spence (1976). When production costs are high and consequently so also certificate prices retailers will find it profitable to use saved certificates or borrow ones from future compliance periods rendering the production of green certificate during this period to fall below the quota level. And, when costs and hence prices are low, producers of green electricity as well as retailers find it in their interest to save certificates for future use. Such, banking of certificates implies that the production of green electricity during the compliance period exceeds the quota level.

Also a competitive bidding system may be designed in ways improving its ability to deal with uncertainty. It is possible to let the amount procured be a function of the bids (which signal about the state of the world) so that larger (smaller) quantities are procured when costs of green electricity turn out to be lower (higher) than expected.

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[6] It is of importance that the revenues from the safety valve or the penalty fee are not transferred to the producers of green electricity, something that has been suggested for the Swedish certificate system. This would create contra-productive incentives. The most profitable strategy for the green producers would then be to produce nothing, whereby they would incur no cost but would receive revenues equal to the penalty fee times the quota.

The discussion above leads to the conclusion that quantity-based policies – in contrast to what the literature on policy instruments promoting green electricity seems to indicate – can be designed in ways making them superior to a fixed feed-in tariff. It should be noted that we here have assumed that only marginal costs of green electricity are uncertain. However, as indicated by Figure 1, the market for green electricity is not only affected by variations in marginal costs of green electricity but also by variations in marginal costs of conventional electricity and, under some instruments, also by variations in the demand for electricity. How this affects the relative performance of various instruments to promote green electricity is something the literature seems to have overlooked. In the next sub-section we identify the effects of uncertainty regarding the costs of conventional electricity. The effects of not knowing future electricity demand is studied in the sub-section thereafter.

Uncertain marginal cost of conventional electricity

Consider now the case where the uncertainty only refers to the location of the MC_{conv} function. This case is depicted in Figure 3, where it is assumed that the cost function can take either one of three equally likely locations, high, as expected and low.

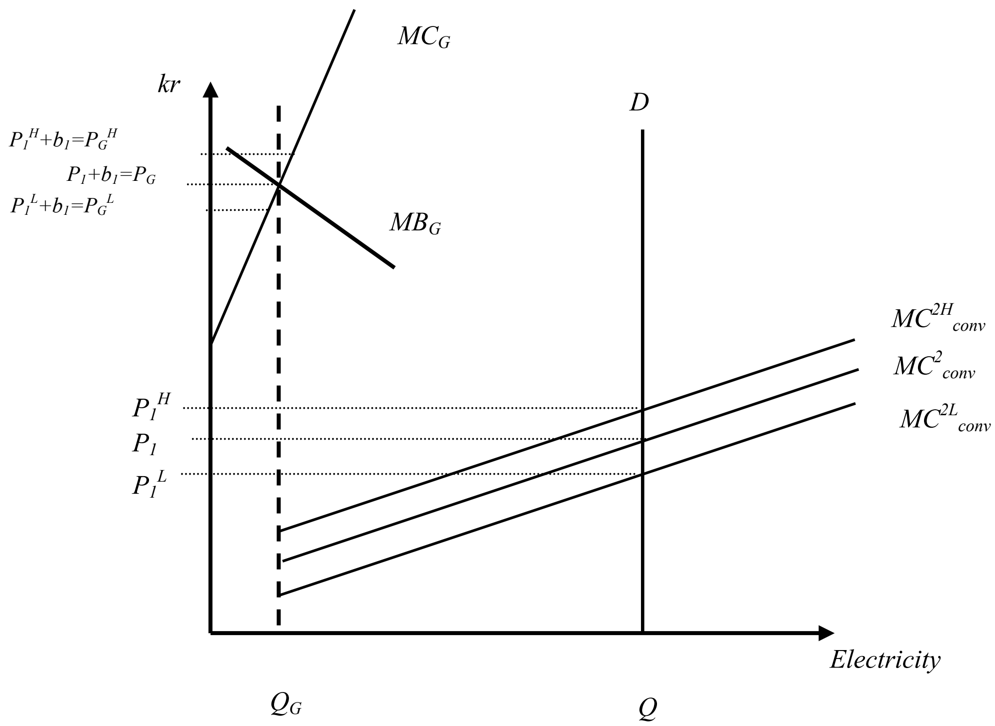

Figure 3 Uncertain costs of conventional electricity

Since the MC_G function here does not vary with the state of the world the regulator would, by choosing Q_G as the target level in the q-based policies, induce the efficient level of green electricity. Given this production of green electricity, the producer price on conventional electricity would be P_I^L, P_I and P_I^H, depending on which MC_G function that is being realized. Since the producer price on electricity varies with the state of the world so will the certificate price. Uncertain future certificate prices has by some analysts been interpreted as implying that also the proceedings from investments in green production capacity will be uncertain, see *e.g.* Energimyndigheten (2004). However, Figure 3 shows that this need not be the case. As long as the MC_G function is constant over the states of the world so will also the per unit revenue required to induce Q_G units be. In other words, the sum of realized electricity price and realized certificate price will be constant, *i.e.*, $P_I^L + t_I^L = P_I + t_I = P_I^H + t_I^H = P_G$.

Also the feed-in tariff P_G will induce the efficient production of Q_G units.

The environmental bonus b_I, on the other hand, implies a total per unit revenue of green electricity that varies with the state of the world. Consequently, the production volume induced will also vary. As shown in Figure 3, when marginal costs of conventional electricity are higher, equal to or lower than expected, total per unit revenue will amount to $P_I^H + b_I$, $P_I + b_I$ and $P_I^L + b_I$, respectively. Thus, the bonus b_I will induce more (less) than Q_G units of green electricity when marginal costs of conventional electricity exceeds (fall below) the expected level. So, when only marginal costs of conventional electricity are uncertain all instruments but the environmental bonus will be efficient.

If also the costs of green electricity are uncertain the picture becomes more complicated. Given our assumptions, there are now nine possible states of the world. We know from the preceding sub-section that when marginal costs of green electricity is uncertain no instrument is able to induce the efficient outcome in all state of the world. It should be noted that only the performance of the environmental bonus is affected by uncertainty regarding the marginal costs of conventional electricity. So, expected efficiency loss of the quantity-based instruments and the feed-in tariff would also in this case equal X and Y, respectively.

It is possible that the environmental bonus b_I performs better than the other instruments when also the costs of conventional electricity are uncertain. Such an outcome is illustrated in Figure 3, where the bonus is assumed to give A, Q_G and B units of green electricity when the MC_{conv} function is higher, equal to and lower than expected, respectively. Since A (B) lies closer to the efficient production level when marginal costs of green electricity are high (low) than do the production levels induced by the feed-in tariff or the quantity-based instruments, the efficiency losses under the environmental bonus are smaller than those following the feed-in tariff (the striped areas) or the quantity-based policies (the grey areas). However, it must be emphasized that although possible, this outcome is not likely. It requires (a) a positive covariance between the stochastic elements in MC_{conv} and MC_G, *i.e.*, when MC_G^H there must be a tendency for MC_{conv} to be lower than expected, and (b) that the variance of MC_{conv} is not too small or too large in relation to the variance of MC_G. If these pre-requisites are not at hand, the bonus will have larger expected efficiency losses than the other instruments.

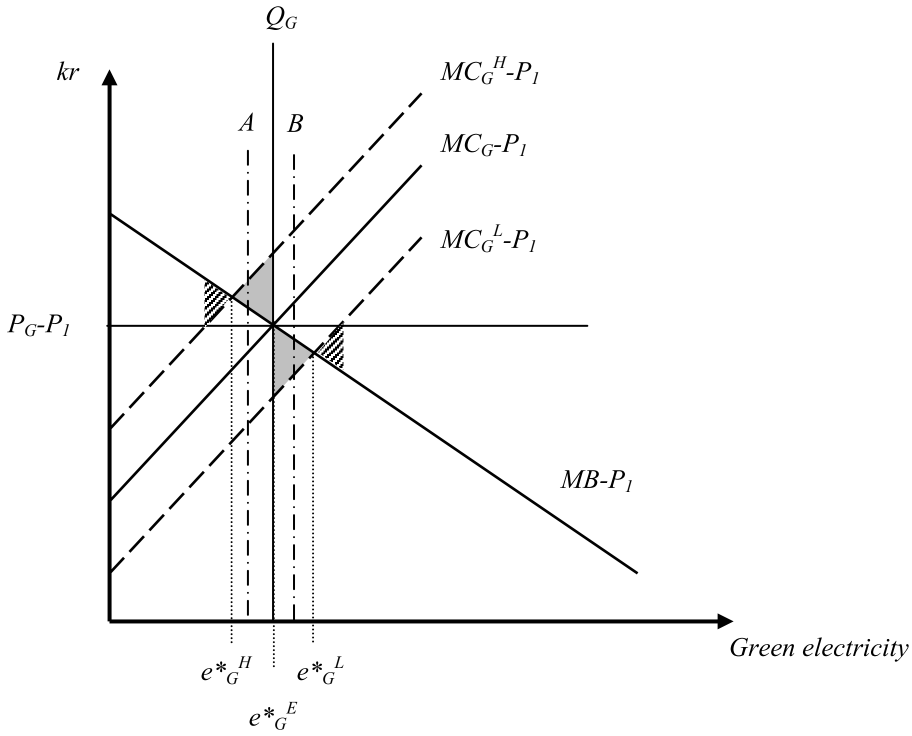

Figure 4. Uncertain marginal costs of green and conventional electricity

We now turn to discuss the effects of a safety valve when both the MC_G and the MC_{conv} functions are uncertain. Now, high certificate prices need not only reflect high production costs of green electricity but also low marginal cost of conventional electricity. Hence, the safety valve may now enter into effect for the wrong reason, which might result in a larger efficiency loss than what would have materialized had there been no safety valve. To see this, consider Figure 3 and a safety valve that equals to P_G-P_1. Then, if MC_G as expected but MC_{conv} lower than expected, this safety valve would enter into force and induce a total per unit revenue for green electricity lower than P_G. Hence, the production of green electricity would fall below the efficient level of Q_G units. The higher the safety valve is the smaller is this efficiency loss, implying that uncertainty regarding future costs of conventional electricity has an incremental effect on the optimal safety valve.

Uncertain electricity consumption

Assume now, to begin with, that only the location of the demand function for electricity is uncertain. This situation is portrayed in Figure 5, where it is assumed that the function can take either one of three equally likely locations – higher than, equal to and lower than *D*. Hence, *D* is the expected location. The feed-in tariff system and the bidding system are unaffected by this type of uncertainty. However, green certificates and the environmental bonus are not. In the case of certificates the consumption of electricity determines how much green electricity the system mills in, *i.e.*, Q_G^L ($=\alpha Q_L$), Q_G ($=\alpha Q$) and Q_G^H ($=\alpha Q_H$). Since the MC_G function does not vary, Q_G is the efficient production level in all states of the world. Hence, we have here established that the certificate system results in efficiency losses whenever the electricity consumption deviates from its expected level.

Higher electricity consumption implies in general a higher electricity price. A given environmental bonus will therefore render the per unit revenue of green electricity to vary with the electricity demand whereby also the induced production level will vary with electricity consumption. As we have drawn Figure 5 these variations are rather small and therefore not marked in the Figure. Nevertheless, also the environmental bonus b_1 will produce efficiency losses.

What we here have shown is that when only the future demand for electricity is not fully unknown both the certificate system and the environmental bonus will be inferior to the feed-in tariff or the competitive bidding system.

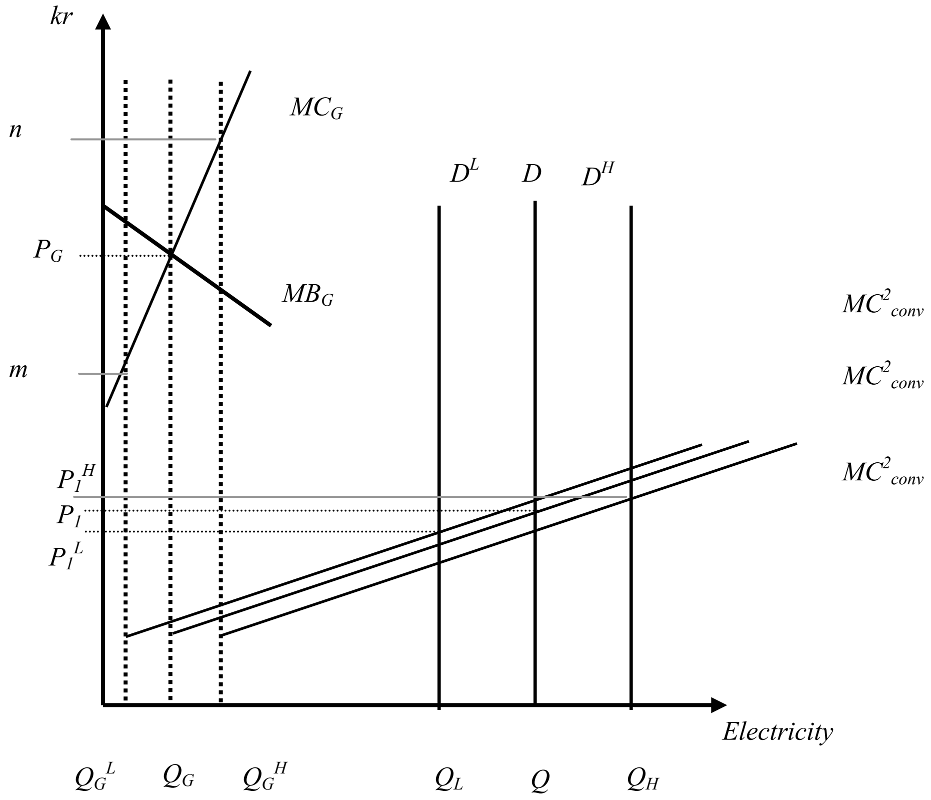

Figure 5. Uncertain demand for electricity

Assume now that also MC_G is uncertain. In this case all four instruments will result in efficiency losses whenever the MC_G function deviates from its expected location. The outcomes under the competitive bidding scheme or the fixed feed-in tariff are, however, not affected by variations in the electricity consumption. Therefore, the efficiency losses of a bidding system procuring Q_G units when costs turn out to be higher (lower) than expected correspond to left (right) grey triangle in Figure 6. The expected loss then equals *X.* The efficiency losses under the feed-in tariff P_G corresponds to the striped areas in the Figure, which gives the expected loss *Y.*

When also the demand for electricity is uncertain a certificate system might perform better than the instruments just mentioned. This would happen if it induces *A* units when MC_G^H and *B* units when MC_G^L – production levels rather close to the efficient levels of $e*_G^H$ and $e*_G^L$. So, for the certificate system perform to perform better than the competitive bidding system high electricity demand must be associated with low marginal costs of green electricity, and *vise versa, i.e,* the covariance between *D* and MC_G has to be negative. Also the environmental bonus may induce production of green electricity close to the efficient levels. For this to be the case, high electricity demand must be associated with high marginal costs of green electricity, and *vise versa, i.e.,* the covariance between D and MC_G must be positive. Hence, these two happenings cannot occur at the same time.

Even if it is conceivable that a certificate system could perform better than a feed-in tariff or a competitive bidding system, this is by no means a likely outcome. First the variations in the electricity demand must not be too large. If large then the certificate system would yield a quota obligation producing efficiency losses much larger than those obtained under the other instruments. And, it is not easy to find theoretical reasons for why there would be a negative covariance between the stochastic elements of MC_G and D. Thus, the outcome MC_G^L and D^L is as likely as any other outcome. In this outcome, the certificate system would induce B units while the efficient amount is $q^*{}_G^L$, resulting in a large efficiency loss. Hence, the principal effect of letting the target level in a certificate system depend on the electricity consumption is a higher risk of large efficiency losses and a higher expected efficiency loss.

A safety valve would only prevent us from some of the efficiency losses that are associated with high certificate prices. Thus, given the lack of arguments for why (a) the covariance between MC_G and D would be efficiency enhancing and/or (b) the MB function would vary in a efficiency enhancing way, one has to question the reasonable in letting the target level of the certificate system to be a function of the electricity consumption. A fixed target level would seem to yield lower expected efficiency losses, especially if combined with a safety valve and opportunities to banking and borrowing of certificates.

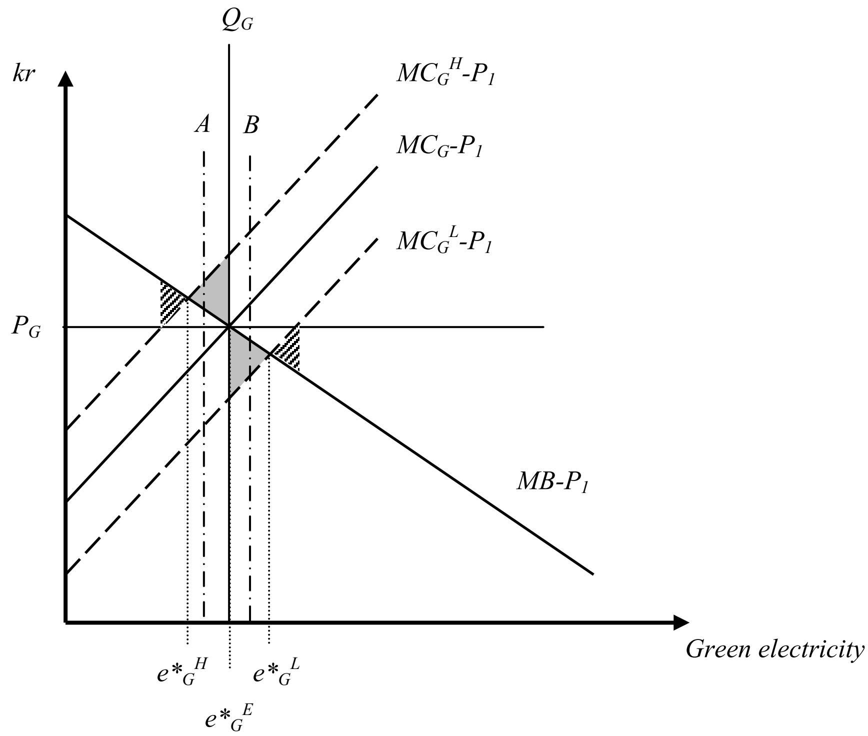

Figure 6. Uncertain demand for electricity and costs of green electricity

4. Concluding Remarks

It has in the literature on instruments to promote production of green electricity been suggested that price-based policies (*e.g.*, fixed-in tariffs) would be superior to quantity-based policies (*e.g.,* an obligation on retailers of electricity to procure a given amount of green electricity). The stated reason is that quantity-based policies tend to induce too much (little) green electricity whenever production costs turn out to be higher (lower) than expected. However, price-based policies, on the other hand, induces too little (much) green electricity, and, as shown here quantity-based policies can be designed in ways making them superior to a fixed feed-in tariff in the sense of yielding a smaller expected efficiency loss.

It is also shown here that green electricity certificate system and systems with so-called environmental bonuses are more complicated policy instruments than so far has been recognized. If future electricity prices are highly uncertain, an environmental bonus is likely to be inferior to the other instruments investigated here – a feed-in tariff, a competitive procurement of a given quantity green electricity and a green certificate system. If on the other hand, future electricity consumption is highly uncertain, a certificate system with a quota obligation depending on the consumption level is likely to be the inferior instrument.

Only if it can be argued that the stochastic elements of future costs of green electricity and the future electricity demand co-vary in certain ways or that the societal benefits of green electricity increases in the consumption of electricity, is there a rationale for certificate systems of the type currently in use in Sweden and several other countries. Given the absence of such arguments, it should be considered to fixate the quota obligation. A system with a fixed quota obligation in combination with a so-called safety valve and opportunities to transfer certificates across compliance periods seem to be the most efficient policy instrument. Such a system would protect the society from outcomes where, at the margin, units of green electricity are milled in at costs by far exceeding the societal benefit of these units.

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